

magnetized by a not very powerfully excited helix surrounding it. In the recent experiments the magnetizing force was (we may infer) far greater.

It is to be remarked that the results now brought forward do not afford ground for a quantitative comparison between the effects of the same degree of magnetism, on the resistance to electric conduction along and across the lines of magnetization, in either one metal or the other, in consequence of the oblong form of the specimens used in the experiment. It is probable that in each metal, but especially in the nickel of which the specific inductive capacity is less than that of iron, the transverse magnetization was more intense than the longitudinal magnetization, since the poles of the electro-magnet were brought closer for the former than for the latter.

I hope before long to be able to make a strict comparison between the two effects for iron at least, if not for nickel also; and to find for each metal something of the law of variation of the conductivity with magnetizing forces of different strengths.

XX. "On the Electric Conductivity of Commercial Copper of various kinds." By Professor W. THOMSON, F.R.S.
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In measuring the resistances of wires manufactured for submarine telegraphs, I was surprised to find differences between different specimens so great as most materially to affect their value in the electrical operations for which they are designed. It seemed at first that the process of twisting into wire-rope and covering with gutta-percha, to which some of the specimens had been subjected, must be looked to to find the explanation of these differences. After, however, a careful examination of copper-wire strands, some covered, some uncovered, some varnished with india-rubber, and some oxidized by ignition in a hot flame, it was ascertained that none of these circumstances produced any sensible influence on the whole resistance; and it was found that the wire-rope prepared for the Atlantic cable (No. 14 gauge, composed of seven No. 22 wires, and weighing altogether from 109 to 125 grains per foot) conducted about as well, on the average, as solid wire of the same mass: but, in the larger collection

of specimens which thus came to be tested, still greater differences in conducting power were discovered than any previously observed. It appeared now certain that these differences were owing to different qualities of the copper wire itself, and it became important to find how wire of the best quality could be procured. Accordingly, samples of simple No. 22 wire, and of strand spun from it, distinguished according to the manufactories from which they were supplied, were next tested, and the following results were obtained :—

Table of relative conducting qualities of single No. 22 Copper wire, supplied from manufactories A, B, C, D.

	Resistances of equal lengths.	Weights of seven feet.	Resistances re- duced to equal conducting masses and lengths.	Conducting power (reciprocals of resistances) of equal and similar masses.
A. .	100	121·2 grs.	100	100
B. .	100·2	125·8 „	104·0	96·05
C. .	111·6	120·0 „	110·5	90·5
D. .	197·6	111·7 „	182·0	54·9

The strands spun from wire of the same manufactories showed nearly the same relative qualities, with the exception of an inversion as regards the manufactories B and D, which I have been led to believe must have arisen from an accidental change of labels before the specimens came into my hands.

Two other samples chosen at random about ten days later, out of large stocks of wire supplied from each of the same four manufactories, were tested with different instruments, and exhibited, as nearly as could be estimated, the same relative qualities. It seems, therefore, that there is some degree of constancy in the quality of wire supplied from the same manufactory, while there is vast superiority in the produce of some manufactories over that of others. It has only to be remarked, that *a submarine telegraph constructed with copper wire of the quality of the manufactory A of only $\frac{1}{21}$ of an inch in diameter, covered with gutta-percha to a diameter of a quarter of an inch, would, with the same electrical power, and the same instruments, do more telegraphic work than one constructed with copper wire of the quality D, of $\frac{1}{16}$ of an inch diameter,*

covered with gutta-percha to a diameter of a third of an inch, to show how important it is to shareholders in submarine telegraph companies that only the best copper wire should be admitted for their use. When the importance of the object is recognized, there can be little difficulty in finding how the best, or nearly the best, wire is to be uniformly obtained, seeing that all the specimens of two of the manufactories which have as yet been examined have proved to be of the best, or little short of the best quality, while those of the others have been found inferior in nearly constant proportion.

What is the cause of these differences in electrical quality is a question not only of much practical importance, but of high scientific interest. If chemical composition is to be looked to for the explanation, very slight deviations from perfect purity must be sufficient to produce great effects on the electric conductivity of copper; the following being the results of an assay by Messrs. Matthey and Johnson, made on one of the specimens of copper wire which I had found to be of low conducting power :—

Copper	99·75
Lead	·21
Iron	·03
Tin or antimony	·01
	100·00

The whole stock of wire from which the samples experimented on were taken, has been supplied by the different manufacturers as remarkably pure; and being found satisfactory in mechanical qualities, had never been suspected to present any want of uniformity as to value for telegraphic purposes, when I first discovered the difference in conductivity referred to above. That even the worst of them are superior in conducting power to some other qualities of commercial copper, although not superior to all ordinary copper wire, appears from the following set of comparisons which I have had made between specimens of the No. 22 A wire, ordinary copper wire purchased in Glasgow, fine sheet-copper used in blocks for calico-printers, and common sheet-copper.

Lengths of No. 22 A, weighing 17·3 grs. per foot, used as standards.	Conductors tested.	Their weights per foot.	Lengths resisting as much as standards if of equal conduc- tivity.	Lengths found by experiment to re- sist as much as standards.	Conductivity re- ferred to that of No. 22 A as 100.
inches.		grs.	inches.	inches.	
23·8	Ordinary No. 18 wire.....	57·5	79·0	73·6	93·2
7·5	Slip of fine sheet-copper	37·6	16·3	9·1	55·8
15 5	Slip of common sheet-copper ...	51·1	45·77	15·6	34·1

To test whether or not the mechanical quality of the metal as to hardness or temper had any influence on the electrical conducting power, the following comparison was made between a piece of soft No. 18 wire, and another piece of the same pulled out and hardened by weights applied up to breaking.

Soft No. 18 copper wire.	No. 18 copper wire, stretched to breaking.	Length found equivalent by experiment.
Weight per foot, 57·5 grs.	Weight per foot, 44·8 grs.	24·0 inches.
Length used, 30·8 inches.	Equivalent length, if of equal conductivity, 24·0 inches.	

The result shows that the greatest degree of brittleness produced by tension does not alter the conductivity of the metal by as much as one half per cent. A similar experiment showed no more sensible effect on the conductivity of copper wire to be produced by hammering it flat. There are, no doubt, slight effects on the conductivity of metals, produced by every application and by the altered condition left after the withdrawal of excessive stress*; and I have already made a partial examination of these effects in copper, iron, and platinum wires, and found them to be in all cases so minute, that the present results as to copper wire are only what was to be expected.

To find whether or not there is any sensible loss of conducting power on the whole due to the spiral forms given to the individual wires when spun into a strand, it would be well worth while to compare very carefully the resistances of single wires with those of strands spun from exactly the same stock. This I have not yet had an opportunity of doing; but the following results show that any deficiency which the strand may present when accurately compared with

* See the Bakerian Lecture, "On the Electro-dynamic Qualities of Metals," §§ 104, 105 and 150, Philosophical Transactions for 1856.

solid wire, is nothing in comparison with the differences presented by different samples chosen at random from various stocks of solid wire and strand in the process of preparation for telegraphic purposes.

No. 16 Solid Wire. Pairs of samples in different states of preparation, each 1000 inches long.

Resistances*.	Weights per foot.	Specific resistances reduced to British absolute measure.
	grs.	
Not covered. . . . $\left\{ \begin{array}{l} E_1 \cdot 2036 \\ E_2 \cdot 1995 \end{array} \right\} \cdot 2015$	74·6	11,850,000
Once covered . . . $\left\{ \begin{array}{l} F_1 \cdot 2054 \\ F_2 \cdot 1999 \end{array} \right\} \cdot 2026$	77·55	12,410,000
Twice covered. . . $\left\{ \begin{array}{l} G_1 \cdot 1963 \\ G_2 \cdot 1963 \end{array} \right\} \cdot 1963$	77·2	11,970,000
Thrice covered. . . $\left\{ \begin{array}{l} H_1 \cdot 1893 \\ H_2 \cdot 1916 \end{array} \right\} \cdot 1904$	77·73	11,680,000
Means. 1977	76·78	11,980,000

No. 14 Gauge Strand (seven No. 22 wires twisted together). Pairs of samples in different states of preparation, each 1000 inches long.

Resistances.	Weight per foot.	Specific resistances reduced to British absolute measure.
	grs.	
Not covered. . . . $\left\{ \begin{array}{l} K_1 \cdot 1595 \\ K_2 \cdot 1634 \end{array} \right\} \cdot 1614$	115·82	14,750,000
Once covered . . . $\left\{ \begin{array}{l} L_1 \cdot 1037 \\ L_2 \cdot 1043 \end{array} \right\} \cdot 1040$	109·37	8,964,000
Twice covered. . . $\left\{ \begin{array}{l} M_1 \cdot 1426 \\ M_2 \cdot 1424 \end{array} \right\} \cdot 1425$	111·95	12,590,000
Thrice covered. . . $\left\{ \begin{array}{l} N_1 \cdot 1092 \\ N_2 \cdot 1085 \end{array} \right\} \cdot 1088$	121·30	10,430,000
Means. 1297	114·61	11,680,000

* These resistances were measured, by means of a Joule's tangent galvanometer with a coil of 400 turns of fine wire, in terms of the resistance of a standard conductor as unity. The resistance of this standard has been determined for me in absolute measure through the kindness of Professor W. Weber, and has been found to be 20,055,000 German units $\left(\frac{\text{metre}}{\text{seconds}} \right)$, or 6,580,000 British units

The specific resistances of the specimens of copper wire from the manufactories A, B, C, D, of which a comparative statement is given in the first Table above, I have estimated in absolute measure by comparing each with F_2 , of which the resistance in absolute measure is $6,580,000 \times 1999$, or 1,316,000. The various results reduced to specific resistances per grain of mass per foot of length are collected in the following Table, and shown in order of quality in connexion with four determinations of specific conductivity by Weber.

Specific Conductivities of specimens of Copper expressed in British Absolute Measure.

Description of Metal.	Specific resistances.
Copper wire A No. 22	7,600,000
Wire of electrolytically precipitated copper : Weber (1)	7,924,000
Copper wire B No. 22	7,940,000
Ordinary No. 18 copper wire	8,100,000
Copper wire C No. 22	8,400,000
Weber's copper wire : Weber (2)	8,778,000
No. 14 strand specimen, once covered	8,960,000
Kirchhoff's copper wire : Weber (3)	9,225,000
No. 14 strand specimen, thrice covered	10,400,000
Jacobi's copper wire : Weber (4)	10,870,000
No. 16 wire specimen, thrice covered	11,700,000
Ditto, twice covered	11,970,000
Ditto, not covered	11,850,000
Ditto, once covered	12,410,000
No. 14 strand specimen, twice covered	12,590,000
Slip of fine sheet-copper	13,600,000
Copper wire D No. 22	13,800,000
No. 14 strand specimen, not covered	14,750,000
Slip of common sheet-copper	22,300,000

$\left(\frac{\text{foot}}{\text{seconds}}\right)$. The numbers in the last column, headed "Specific resistances reduced to British measure," express the resistances of conductors composed of ten different qualities of metal, and each one foot long and weighing one grain. It is impossible to over-estimate the great practical value of this system of absolute measurement carried out by Weber into every department of electrical science, after its first introduction into the observations of terrestrial magnetism by Gauss. See "Messungen galvanischen Leitungswiderstände nach einem absoluten Maasse," Poggendorff's Annalen, March 1851. See also the author's articles entitled "On the Mechanical Theory of Electrolysis," and "Application of the Principle of Mechanical Effect to the Measurement of Electromotive Force, and of Galvanic Resistances in Absolute Units," Philosophical Magazine, December 1851.